LITTLE BLUE BOOK NO. 133
Edited by E. Haldeman-Julius

Principles of Electricity

Maynard Shipley

LITTLE BLUE BOOK NO. 133
Edited by E. Haldeman-Julius

Principles of Electricity

Maynard Shipley

HALDEMAN-JULIUS COMPANY
GIRARD, KANSAS

PRINTED IN THE UNITED STATES OF AMERICA

PRINCIPLES OF ELECTRICITY

CONTENTS

PRINCIPLES OF ELECTRICITY

CHAPTER 1

"WHAT IS ELECTRICITY?"

Many persons who have devoted no time to the study of physics wonder what the force is that drives the street-car along—turning its wheels, while at the same time furnishing incandescent lamps (light) for the passengers. They have been told, of course, that the "power" used is "electricity", generated by dynamos "at the power-house", and conveyed to the rapidly moving car by the overhead wire.

"Electricity: yes, but what is electricity?" This is a natural and perfectly legitimate question for a layman to ask.

Scientists and philosophers are asking the same question. But they understand quite well that it is like asking: "What is matter?" Very probably the average inquirer does not ask the question, "What is electricity?" in the same spirit. We can answer one question no better than the other, if the ultimate nature of either matter or electricity is what the inquirer has in mind.

For matter, in the last analysis, *is* electricity. Yet the same person who might ask: "What is electricity?" would not think of asking: "What is matter?" He thinks he knows what matter is —his common sense tells him that *matter is what it appears to be.* "Matter's matter, and there's an end of it."

And just so the physicist insists upon his

common-sense right to reply: "Electricity is electricity." It is what it appears to him to be. And it appears to be a form of *energy*, or a *mode of motion.*

Thales, the reputed founder of Greek science and philosophy, would call electricity "the soul of the universe", because it "endows all things with motion". This "soul", interpenetrating all matter—if not constituting it—is by nature always moving—it is self-moving; motion is part of its very essence. In the lodestone, said Thales, "it moves iron."[1]

As has been said so many times before, Thales was the first to call attention to the fact that amber (fossilized resin), when rubbed with wool or fur, possesses the curious property of attracting small particles, such as straw, pith, lint, dried leaves, etc.;—though there is no reason to suppose that he was the discoverer of this phenomenon. He called the amber *elektron;* and today we call the indivisible corpuscles, or natural unit charges of negative electricity, *electrons*—the true *atoms* of electricity.

But hard rubber, or sealing-wax, is just as "mysterious" as the lodestone (magnetite—natural magnetic iron). Rub the sealing-wax with fur, and it will exhibit all the peculiar properties of the lodestone. Rub glass with silk, and it, too, becomes a lodestone in effect.

[1]If a light piece of iron is placed near a magnet, it moves to the magnet and clings to it; but if the magnet is the lighter of the two bodies, it moves toward the piece of iron.

The ancient Greek philosophers could not explain these phenomena in precise terms.

Empedocles (born between 500 and 480 B. C.) accounted for the attraction of iron to the magnet on the hypothesis that "emanations" or "effluences" from the magnet penetrate into the "symmetrical pores" of the iron, drawing the iron itself and holding it fast. The concept "electricity" was unknown to the Greeks. But it is possible that Empedocles had in mind some such "effluence" or "emanation" as the "fluid" electricity of Benjamin Franklin (1706-1790) and his successors.

The soul-force ("moving power") of Thales—always moving and causing movement—and the "effluences" of Empedocles have become the "field of force" of Faraday, Sir J. J. Thomson, and Sir Oliver Lodge. The self-moving "soul" of nature, manifest in the lodestone, or acting on the lodestone, or on the particles said to be "attracted" by the lodestone, is but a synonym for the lines of force of the magnetic field of modern physics. Thales and Empedocles spoke in the language (terminology) of their day and age. The "emanations" of Empedocles are the "corpuscles" of Thomson—a body becoming positively electrified by "losing some of its corpuscles", and hence capable of drawing negatively charged particles to itself.

Electricity and magnetism are related but not identical. A moving magnet can induce an electric current in a wire, and an electric current can produce magnetism in iron. The construction of telegraph and telephone instruments depends on the fact that an electric cur-

rent can produce magnetism and that magnetism can produce an electric current.

We know *effects* which we call "electricity", just as we know the phenomena associated with living protoplasm without knowing what "life" is. It may be that "life" and "electricity", as well as "electricity" and "magnetism", are all different aspects of the same thing.

Today we say, in the words of Dr. Charles P. Steinmetz ("Relativity and Space", Pages 18-19):—

"The space surrounding a magnet is a magnetic field. If we electrify a piece of sealing-wax by rubbing it, it surrounds itself by a dielectric or electrostatic field, and bodies susceptible to electrostatic forces—such as light pieces of paper—are attracted. The earth is surrounded by a gravitational field, the lines of gravitational force issuing radially from the earth. If a stone falls to the earth, it is due to the stone's being in the gravitational field of the earth and being acted upon by it."

Again:—"Suppose we have a permanent bar magnet and bring a piece of iron near it. It is attracted, or moved; that is, a force is exerted on it. We bring a piece of copper near the magnet, and nothing happens. We say that the space surrounding the magnet is a *magnetic field*. A *field*, or *field of force*, we define as 'a condition in space exerting a force on a body susceptible to this field'. Thus, a piece of iron being magnetizable—that is, susceptible to a magnetic field—will be acted upon; a piece of copper, not being magnetizable, shows no action. ..... To produce a field of force requires

energy, and this energy is stored in the space we call the field. Thus we can go further and define the field as '*a condition of energy storage in space exerting a force on a body susceptible to this energy*'."

Thales said that the "divine moving power", the soul of nature, under certain conditions "moves iron", through the mysterious properties of the lodestone. Modern science, borrowing from Aristotle the term *energia*, substitutes for "soul of nature" the single word *energy*. Aristotle declared that "not capacity, but energy ..... is the first principle anterior to and superior to anything else" (*Metaphysics* xii, 7: cf. also *Physics* ii, 9, 6).

Modern science describes in more precise phrases what *occurs* when a body susceptible to the influence of the magnet is brought into proximity to a lodestone (magnetite). It gives us a picture of "lines of force" (energy) in a defined "field". But it tells us no more about what energy *is* than Thales tells us what his "moving power" is. Dr. Steinmetz tells us that "energy is the only real existing entity, the primary conception, which exists for us because our senses respond to it" (*Op. cit.*, Page 23). For Thales the universal "moving power" of nature operates *on* or *in* all matter; for the physicist of today the moving power (energy) *is* matter—man's perception of matter being the response of his senses to the vibrations of energy. "All sense perceptions are exclusively energy effects," and "energy is the only real existing entity."

Thales may or may not have considered the

cosmos as "matter" *and* "soul" or "moving power". In any event the pre-Socratic Ionian philosophers recognized no distinction between matter and soul in our modern sense. The moving power of nature (soul) was as much a material substance as gross matter itself, only more rarefied, more elusive. It was equivalent to the "energy"—electricity—of modern science.

Here we have, then, the answer to the question: "What is electricity?" It is *energy*—"the only real existing entity, the primary conception, which exists for us because our senses respond to it." "All sense perceptions are exclusively energy effects." This is the answer to the question: "What are the Hertzian waves, used in 'wireless'?" It is the answer also to the question: "What is light?" as well as "What is electricity?" By carrying the explanation of the beam of light and the electromagnetic wave (like that of the radio communication station or that surrounding a power transmission line) back to the *energy* field (or, less accurately, the field of force), we have carried it back, as Dr. Steinmetz well declared, as far as possible, "to the fundamental or primary conceptions of the human mind, the perceptions of the senses."

All that we know of the world is derived from the *perceptions of our senses*, which are for us the only *real facts*, all things else being conclusions from them; and "all sense perceptions are exclusively *energy* effects." Electricity is an energy effect, perceived by our senses. No other definition or explanation can or need be given, since *energy is the primary concep-*

tion. And this explains also what matter is, since *energy* and *matter* are interchangeable—or equivalent—terms. What we call electricity is one of the *effects of energy* on our senses. In itself, it *is* energy, the stuff that matter is made of; at once the "moving power" and the thing moved.

Everything has been said that can be said now as to what electricity *is*: our concern in the remainder of this volume will be to discover what electricity *does* and how it acts.

The reader of this little book who may be more or less familiar with larger volumes dealing with electricity, energy, electrons, electro-magnetic waves or oscillations, magnetic and dielectric fields (usually combined), light-waves, etc., will notice that no mention has been made of the classical ether hypothesis, the universal *plenum* in which energy is said to be stored, and in which transverse waves of light are said to occur, ether atoms or vibrations moving at right angles (perpendicularly) to the light-beam.

Now, transverse waves can exist only in rigid (solid) bodies. The universal ether of space, referred to in the text-books, must—for reasons which I need not discuss here—be a solid body of a rigidity much greater than that of steel, while at the same time possessing a very great elasticity so that bodies (such as the planets) moving through it meet with no resistance, no friction. The electron theory of Lorentz, Larmor, Thomson, Lodge and others is based upon the assumption that such a

plenum, or medium, is a real substance. As a matter of fact, it is not known that any such medium (or ether) does exist, and it is now recognized that while light is a *wave*, a periodic phenomenon, like an alternating current, it is not necessarily a wave *motion* of something or in something, any more than it is necessary to assume the alternating current or voltage wave to be a motion of matter.

Electrical engineers make no assumption regarding the existence of an ether filling all space and interpenetrating all matter—have no need for an ether as the hypothetical carrier of the electric wave. And just so the physicist of today has no real need for the classical assumption that the light-wave is a wave motion of or in something of great rigidity yet highly elastic and frictionless, filling all space. Light is now known to be a high-frequency electromagnetic wave, and cannot logically be considered as a wave motion of a hypothetical ether. "The ether thus vanishes, following the phlogistin and other antiquated conceptions."[2] As Prof. A. S. Eddington remarks in his "Report on the Relativity Theory of Gravitation" (1920), "Light does not cause electromagnetic oscillations; it *is* the oscillations."

We know nothing whatever about the so-

---

[2]Steinmetz, Dr. Charles P., "Four Lectures on Relativity and Space," Pages 21-22, London and New York, 1923. See Lecture II, "Conclusions from the Relativity Theory," Pages 12-45. See also, Campbell, Dr. Norman R., "Modern Electrical Theory. Supplementary Chapters: Relativity," Cambridge University Press, 1923.

called ether of space; but we can formulate very clearly "The Principles of Electricity" without the aid of that hypothesis.[3]

CHAPTER 2

MAGNETIC PHENOMENA

It was long ago observed that if glass is rubbed by silk, or a piece of sealing-wax or hard rubber by fur or wool, an effect occurs similar to that noted by Thales when amber is rubbed by similar materials—i. e., light bodies such as bits of dry paper, pith, etc., will cling to the surface of the substance. After coming in contact with the attracting substance, the bits of paper, straw, etc., are then repelled.

If a ball made of pith be suspended at the end of a silk thread, and a glass rod which has just been rubbed with silk be brought close to the ball, the pith-ball immediately flies to the rod, clinging to it for a time. Then it jumps away, and instead of hanging vertically, seems

[3]Cf. Whittaker, E. T., "A History of the Theories of the Ether and Electricity from the Age of Descartes to the Close of the Nineteenth Century," Dublin and London, 1910. See also, Comstock and Troland, "The Nature of Matter and Electricity," New York, 1917; Steinmetz, Dr. Charles P., "Elementary Lectures on Electric Discharges, Waves and Impulses and Other Transients," New York, 1914; and Starling, Dr. Sydney G., "Electricity," London and New York, 1922.

to be pushed away from the glass by a mysterious force. A second ball, treated like the first, and brought near the first, is violently repelled. But if one ball is charged from the glass and one from the wax, they attract instead of repelling each other. Two pieces of glass or two pieces of wax repel each other.

A similar attraction and repulsion was early observed between the poles of the magnet. This influence seems to be transmitted by some invisible agency or medium across the intervening space between the bodies, and in this respect the force does not differ from that acting between the moon and the earth, or the earth and the sun. And just so, if a light piece of iron is placed near a magnet, it moves to the magnet and clings to it; but if the magnet is the lighter of the two bodies, it moves toward the piece of iron.

Although Thales had attempted to explain the cause or nature of magnetic attraction as long ago as the end of the seventh century B. C., or in the first quarter of the sixth century (about 2,500 years ago), it was not until the year 1582 A. D. that Dr. William Gilbert (1540-1603), of Colchester, physician to Queen Elizabeth, made the first experimental study of magnetic phenomena. It is to Dr. Gilbert that we owe the name *electricity* as applied to this force, derived from his *vis electrica.*

By 1600, Dr. Gilbert had published his epochal work "*De Magnete*", which not only contained the first rational treatment of mag-

netic and electrical phenomena, but was also virtually the first scientific work published in England. It is to this truly great treatise that must be traced the beginnings of the science of electricity.[4]

Throwing aside, as useless, mere philosophical speculation as to the nature of magnets, Gilbert explained in his book how practical experiments should be carried out. He insisted that it is to nature herself that we must apply for the answers to problems in "natural history". Gilbert's particular objective was not, however, discovery of the laws of magnetism or electricity; what he most desired to learn was *the composition of the earth*: he wished to know through actual research just what is its innermost constitution. His experiments led him to the conclusion that *the earth is a magnet*. It may, indeed, be considered a huge spheroidal lodestone.

Gilbert told his readers to take a piece of lodestone (natural magnetic iron) of convenient size, turn it on a lathe to the form of a ball, then place on the *terella* (as he called the spherical lodestone) a piece of iron wire. It

[4]On the Continent, experimental work in other fields was already in progress, thanks to the genius of Descartes, Galileo and other founders of modern science. Gilbert, like Harvey, spent some years in Italy, coming under the direct influence of the great Italian physicist-astronomer-physician Galileo. Harvey was in Padua (1598-1602) during Galileo's professoriate. The introduction of scientific methods in England at this time may well be credited to Italian and French influences.

will then be observed that the ends of the wire "move round its middle point."[5]

Lodestones, fragments of magnetite (Fe_3O_4), are said to have been first discovered at Magnesia, in Asia Minor,—hence the word *magnetism.* Some of the earliest references to the lodestone relate to its property of lying in a north-and-south direction when an elongate stone is freely suspended, one particular end always pointing northward, just as the great magnet the earth, or the mariner's compass-needle, has two opposite magnetic poles. The location of the poles of a disk-shaped stone is readily found by turning it round in the presence of a compass-needle.[6]

Iron and steel are more strongly magnetic than any other metals. While only one kind of iron ore is naturally magnetic—forming magnets—the property of magnetism may always be given to any kind of iron or steel. One need only strike an iron bar while it is lying in a north-south position, or rub the iron with a magnet, and it becomes a magnet. If it is desired to make a *permanent* magnet, steel must be employed. A compass-needle is therefore made of magnetized steel. If balanced upon a pivot, the positive pole of the needle will point

[5]Gilbert's book is usually referred to simply as "The Magnet," but the full title is: "Concerning the Magnet and Magnetic Bodies, and Concerning the Great Magnet the Earth: A New Natural History (Physiologia) Demonstrated by Many Arguments and Experiments."

[6]Magnetite does not always possess polarity. It is called "lodestone" only when it does. It occurs not only in the form of more or less massive stones, but also as loose sand and in earthy forms.

(roughly) towards the earth's north geographical pole.[7]

A compass-needle is also a "dipping needle", unless the suspended magnetized needle lies about half way between the earth's magnetic poles. The north magnetic pole lies below the earth's surface—at an unknown depth—at the extreme northeastern corner of the continent of North America; and the corresponding south magnetic pole on the edge of the Antarctic continent—King George's Land—about 2,300 miles south of Australia. These magnetic poles do not correspond even roughly with the geographic poles, nor does the magnetic equator by any means correspond with the geographic equator.

Only a small section of the magnetic equator runs north of the true (geographic) equator—e. g., from the coast of Brazil to the coast of Kamerun (Africa).

According to Prof. T. J. J. See, "the whole magnetic system has been pushed southward 200 miles by bodily displacement of both poles towards the ocean hemisphere." This eminent physicist-astronomer also stated (in 1922) that his researches led him to the discovery that the two magnetic poles are at unequal depths in the earth, the North Pole being much deeper than the South Pole, "with the result that the total magnetic forces in the southern hem-

---

[7]The fact that a lodestone possesses two "poles" was discovered in the thirteenth century by Petrus Peregrinus, of Picardy, while he was experimenting with a spherical lodestone and a needle.

isphere are considerably stronger than in the northern hemisphere."[8]

It was long ago discovered that if one starts northward from the magnetic equator, the compass-needle soon begins to dip downward (and northward). At the southern border of the United States, the downward inclination amounts to about 57 degrees. At the borders of North Dakota and Maine the dip is about 76 degrees. By the time Hudson Bay is reached the needle assumes a vertical position. This means that it is here suspended immediately over the north magnetic pole itself. At the magnetic equator in Peru, a needle suspended by a thread is exactly balanced. Dr. See states that at the North and South Poles there is a downward pull—by the magnetic force—of just one millionth of the gravitational force, while in Peru the total magnetic force is precisely one ten millionths of gravitation.

It has been found that both the North and the South Poles are anything but fixed in position. They "wander about in their subterranean region". In the course of centuries, the

[8]From notes taken at a lecture by Dr. See before the California Academy of Sciences in 1922. Dr. See, in charge of the United States Naval Observatory at Mare Island (California), presented in the lecture "A New Theory of the Ether," in which he outlined the grounds upon which he based his new theory of a direct connection between magnetism and universal gravitation. It is highly interesting, in this connection, to learn that Dr. Albert Einstein, in collaboration with Professor Eddington (of Cambridge)—working on the principle of Relativity—has discovered a connection between the earth's power of attraction (gravitation) and electricity.

compass-needle swings from west of north, and then to the east. Even the amount of the dip slowly changes, in a periodic way, and at every point on the earth. For example, in 1576, the north end of the needle at London dipped at an angle of 71 degrees 50 minutes. By 1720 the angle had increased to 74 degrees 42 minutes —almost up and down. Since then, the dip at London has continually decreased. At the present time we are puzzled by the fact that the inclination of the dip is 66½ degrees at London and more than 70 degrees at Washington.

It has long been known that variations in magnetic declination of the delicately mounted needles, in observatories, are directly correlated with solar disturbances. The late Dr. A. Wolfer (sometime director of the Zurich Observatory) was the first to show us how closely the curve of the sun-spot activity rises and falls with the fluctuations of magnetic declinations.

Before attempting to explain the peculiarities of magnetic action in terms of the modern electromagnetic theory, it will be well to recall certain stages of progress in the development of this theory. This plan will permit elucidation of the theory itself by "easy steps".

CHAPTER 3

PIONEERS IN ELECTROMAGNETIC THEORY

The Danish physicist, Hans Christian Örsted, professor of natural philosophy at the University of Copenhagen, showed us, more than a century ago, that a magnetic needle can be deflected by an electric current. He had been

led by theoretical considerations to assume that there must be a correlation between electric and magnetic forces. While yet a young man, Örsted endeavored by persevering experimentation to prove the correctness of his theory. While he did not expect a parallel action of the two forces, he was firmly convinced that magnetism and electricity were inseparable twins.

He noted that both heat and light radiated from a conductor when heated to incandescence. He also assumed that magnetic forces are radiated from a conductor traversed by electricity.

In 1820, while lecturing before his class, he became convinced that the apparatus he was then using could be made to demonstrate the correctness of his views. He asked his pupils to accompany him to his laboratory, where, as he predicted, a slight deflection of the magnetic needle, turned at right angles to the electric current, was shown when placed close to the copper wire. Some months afterwards, with a stronger current (made up of twenty cells), he obtained much more intense effects. Investigating these in detail, he found that they met all the requirements of his theory. So, on July 21, 1820, he sent out to the scientific world his now famous circular, "*Experimenta circa effectum conflictus electrici in acum magneticum*" (Experiments on the effect of the electrical conflict in the magnetic needle).

Örsted showed, furthermore, how changes in the position of the magnetic needle occurred with variation of the position of the conductor (copper wire) in regard to it. He demonstrated also that the magnetic effect was not weakened

by insulators—that it would penetrate various materials, whether these were conductors of electric currents or not. He showed that the magnetic field created by the electric current does not have any influence on a needle of non-magnetic material—i. e., brass, glass, etc. It is, in fact, chiefly in the fact that it cannot be insulated that magnetism differs from electricity. It will freely pass through air, stone, mica, glass, clay, brick, or any insulating material.

It is well worthy of especial mention that Örsted employed the term "*conflictus*" to designate the electric current, many decades before the origin of the electron theory of matter. For, on modern theories of electricity, it is the movement to and fro of electric particles (electrons) through the conductor, and their impact ("*conflictus*") that produces what we call electrical phenomena.

Örsted's fundamental discovery of the mutual effects between electricity and magnetism led to further discoveries which made possible the construction of telegraph and telephone instruments, since these depend on the fact that *an electric current can produce magnetism, and that magnetism can produce an electric current.*

If we wind around an iron bar a number of turns of insulated wire, and an electric current is allowed to pass through the coil, the bar becomes a strong electromagnet. But it remains a magnet only as long as the current is passing. Now, the magnetic effects obtained with the electromagnet are identical with those obtained from a permanent magnet—such as

the familiar horseshoe magnet, commonly seen on the flywheel of the Ford automobile, or in the ordinary telephone generator for calling up "Central". In the case of a telegraph instrument, it is important that the iron is a temporary magnet. On the other hand, a permanent magnet is an essential part of every Bell telephone receiver. This permanency is secured by employing a bar of steel instead of a piece of iron—a temporary magnet.

The power produced from a dynamo—or electric generator—depends upon the fact that when a magnet is put into a coil of wire, only a momentary current of electricity passes through the wire, in one direction. If the magnet is withdrawn, a current starts in the opposite direction. Copper wire coiled about an iron core forms the "armature" of the dynamo. The rotating coils are said to "cut the magnetic field." On this principle of electricity, intense electric currents are produced, furnishing the "power" for the electric motors in electric cars, elevators, musical instruments, etc., and for electric lights—incandescent and arc.

Dynamos may contain either permanent magnets or electromagnets. They produce the magnetic field in which the "armature" or conductor—the coils of wire wound around the iron core—rotates. A machine with permanent magnets is usually termed a *magneto*, and is never made in large sizes. The current for the electromagnets may be derived wholly from an outside source, or part of the current which it generates may be used for that purpose.

The current generated in the armature winding is alternating, but may be rectified to a direct current by a *commuter* if desired; otherwise it is conveyed to the line circuit by *collector* or slip rings and brushes.

We owe much of our knowledge of magnetism and electricity to Michael Faraday (1791-1867), who brilliantly covered the whole field of these sciences. Faraday was distinguished alike as a chemist and as an experimenter in electricity and magnetism.

Örsted had shown that magnetism could be produced by a current of electricity, but it remained for Faraday to produce current electricity by a magnetic "field of force", thus laying the foundation for those modern industries which derived motive force for their machinery from the gigantic dynamos of our "power houses".

But I must here introduce a few facts concerning the contributions to electric theory and practice of the great French mathematician and physicist, André Marie Ampère (1775-1836). His discoveries in electrodynamics aided greatly in laying a broad foundation for this science. Very notable was the influence exercised by Ampère on the development of electro-dynamics. And it was he who first clearly established the fact that magnetic action is a peculiar form of electromotive action, and that, in phenomena of this class, "action and reaction are equal and opposite."

From these considerations it was natural for him to suppose that magnetism might be made to produce electricity, as it had already been

shown that electricity might be made to imitate all the effects of magnetism. Numerous attempts were made to effect this predicted result, but for some years all such efforts proved to be fruitless.

Meanwhile the French physicist and astronomer, François Arago (1785-1853), was also conducting experiments with the object of producing electricity by magnetism. One of his experiments actually involved the effect sought, but it was not clearly recognized. Arago observed that the rapid revolution of a conducting plate in the neighborhod of a magnet gave rise to a force acting on the magnet. But it was not recognized by either Arago or other physicists of the day that the forces involved were electric currents—produced by the rapidly revolving conducting plate.

Faraday, in 1831, after several years of preoccupation with other problems, returned to his task of discovering electrodynamical induction, begun in 1825. After a number of fruitless efforts, he was finally rewarded with success, but not in the form which had been anticipated. It was observed that at the precise time of making or breaking the contact which closed the galvanic circuit, a momentary effect was induced in a neighboring wire, which, however, disappeared instantly.[9]

Faraday then discovered that a similar effect could be induc d merely by moving the wire nearer to or farther away from the closed circuit—instead of suddenly making or breaking

[9] *Philosophical Transactions,* Page 127, 1832; First Series, Article 10.

the contact of the "inducing circuit". Later he found that the effects were increased by the proximity of soft iron, and that when the soft iron was affected by on ordinary magnet instead of the voltaic wire, the same effect still recurred. The momentary electric current was produced either by moving the magnet or by moving the wire with reference to the magnet. Finally, it was found that the earth itself might be substituted for a magnet, not only in this experiment but also in others. Mere motion of a wire, under proper conditions, produced the effect.

Here, then, was the true explanation of Arago's experiment: by the rapid revolution of the plate the momentary effect became continuous. Without using the magnet, a revolving plate became an electrical machine. A revolving globe was found to exhibit electro-magnetic action, the circuit being complete in the globe itself without the addition of any wire. It was later found by Faraday that mere motion of the wire of a galvanometer produced an electrodynamic effect upon the needle.[10]

Meanwhile, Ampère, "by a combination of mathematical skill and experimental ingenuity, first proved that two electric currents act on

[10]One of the first electrical experimenters to devise the instrument known as a "galvanometer" was Professor Schweigger, of Halle. There are now eight or more varieties of this instrument (or apparatus) in use. It enables the investigator to measure extremely minute electrodynamic actions, or the very weakest intensity of an electric current, as well as to detect its presence or direction, usually by the deflection of a magnetic needle.

one another, and then analyzed this action into the resultant of a system of push-and-pull forces between the elementary parts of these currents."[11]

Örsted having shown that electric currents produced certain effects on magnets without being in actual contact, and Ampère having demonstrated that magnets can in their turn be supplemented by electric currents,—a magnetic needle being deflected not only by a current passing through a wire, but also by another magnet brought into its neighborhood, and two electric currents acting on one another at a distance—the question now arose as to whether or not electrical attraction and repulsion could be reduced to an action at a distance proportional to the inverse square of the distance.

As early as 1773, Henry Cavendish (1731-1810)—one of the foremost chemists and experimentalists of his day—answered this question affirmatively by experiment.[12] Coulomb (1736-1806)—inventor of the torsion balance—

[11]Maxwell, Clerk, "On Action at a Distance," (*Scientific Papers,* Vol. II, Page 317).

[12]The scientific papers of Cavendish were published (in 1879) under the title, "The Electrical Researches of the Hon. Henry Cavendish," edited by Clerk Maxwell. Cavendish anticipated many later investigations of British and Continental writers, including Ohm's law—i. e., the proportionality between the electromotive force and the current in the same conductor; and anticipated also Faraday's discovery of the specific inductive capacity of different substances, even measuring its numerical value in several substances. He had also arrived at the conceptions of electrical capacity and of "potential."

showed that ponderable matter charged with electricity followed the same formula for attraction and repulsion as gravitating bodies did. Poisson (1781-1840) worked out the difficult mathematics of fluids actuated by repelling forces depending on the inverse square of the distance. Laplace (1749-1827) had very early become convinced that the actions of ponderable substances in which electric currents were flowing could be reduced to an action at a distance proportional to the inverse square of the elements of the electric current.

Faraday regarded the electric field as full of lines of electric force, in a state of tension, and naturally repelling each other. To him, as to a number of his contemporaries, the idea of "action at a distance" was repugnant; though such a possibility seemed to be indicated by the action of gravitation—the relation of the forces between two charged bodies to the distance between them being very similar to that of the gravitational forces between two bodies to the distance between them. But Faraday, like the great Descartes long before him, rejected the theory of action at a distance in favor of "action through a medium."

Ampère had sought for some sort of mechanism for the transmission of electromagnetic currents. His own discoveries and those of Örsted led him to formulate the hypothesis that the field in the vicinity of a magnetic body is produced by a number of exceedingly small circular currents which flow undamped in or around the molecules and that magnetization consists merely of the bringing of these

molecular currents into a parallel direction. But it was difficult for some physicists, even in Ampère's day, to accept the hypothesis of undiminished currents *possessing no resistance.*

If we transform the idea of the "molecular currents" of Ampère into the language of today, substituting for these molecular currents electrons revolving in atoms, it can be shown that the great French scientist was substantially correct in his assumptions. In 1915 Dr. Albert Einstein and W. J. de Haas astonished the world of physicists by showing experimentally—by means of a most ingenious apparatus—that the "molecular currents" or revolving electrons really exist.

In 1919, Professor Kramerlingh-Onnes, at the University of Leyden, was able to produce what he called *imitations of ampere currents*—i. e., "undiminished currents producing no resistance." It was demonstrated that the resistance of pure gold and pure platinum differ very little if at all from nil at low temperatures. But wires of these metals, of absolute purity, are difficult to obtain, so mercury was selected for the experiments. The resistance of the metal at the lowest attainable temperature of liquefied helium, −271.5° C., (at a pressure of 3 mm. of the mercury column), proved to be immeasurably small. The resistance down to a position shortly below 4.2° K. (Kelvin's absolute scale) suddenly dropped from a measurable amount to a value practically nil. It was found that the induced current remained in a state of circulation, and that the decrease in

the strength of the current amounted to less than 1 per cent per hour, from which it followed that the "time of relaxation" must amount to more than four days![13]

At the absolute zero of temperature, it is supposed that the orbits of electrons in atoms are perfect circles, whatever their paths may be at measurable temperatures. This motion of the electrons remains when all heat has disappeared, since it is not this motion of the revolution of the electrons in their orbits that is associated with the energy of heat. Heat is *a mode of motion of the atoms themselves*, not of their contained electrons; though increase of heat doubtless results in an increase in the average orbital velocity of the electrons.

Since Ampère's day we have learned at all events, that an electric current means the flow of electrons, either from atom to atom, or passing between the atoms, along conductors. In 1920, Lord Kelvin came to the conclusion that at the absolute zero resistance of metals must be infinitely great, the degrees of dissociation of the electron being, he supposed, nil at the zero hour. If any free electrons remained, he believed they would lose their power of motion, condensing like a vapor upon the metal atoms and freezing fast to them (to borrow a phrase from Kamerlingh-Onnes). The experiments of the c lebrated Holland physicist show that the resistance of metals decreases with lowering of temperature, and would probably become nil at the absolute zero with em-

---

[13]See *Die Naturwissenschaften* (Berlin), January 28, 1921.

ployment of a perfectly pure platinum wire. If this is true, then would a current of electricity, once set up in a conductor, continue forever?

CHAPTER 4

THEORIES OF ELECTRICITY

The science of electricity is based upon observation of those phenomena of attraction and repulsion which are comprehended under the term *electrostatics*. Statical electricity, so named from a Greek word (statikos), which means "causing to stand (or stay),"—also called *frictional electricity*—is the electricity of stationary charges caused by rubbing together unlike bodies, such as glass and silk (noted in Chapter II). In such cases equal and opposite charges of electricity are always produced. The term *statical electricity* applies properly, however, to the electricity of all stationary charges, however produced.

The electricity upon the surface of glass is called positive electricity; that upon rubber, negative electricity. When silk is rubbed upon glass it receives a negative charge from the glass and confers a positive charge upon the silk. Wool or fur rubbed on wax or rubber receives a positive charge in exchange for a negative charg . "equal and opposite charges of electricity are always produced." A piece of glass and a piece of silk attract one another; two pieces of silk or two pieces of glass or wax repel one another, because a body which is positively charged is attracted by one negatively charged and repelled by one negatively charged, and vice versa. A piece of glass

rubbed by a piece of silk, under suitable conditions, attracts any other body with which it has not been in contact. The piece of silk will do likewise. In all these cases, the attraction or repulsion becomes weaker with increase of distance between the attracting and repelling bodies.

A third body which has been in contact with a piece of glass or a piece of silk acquires to some extent the pr perties of the glass or silk with which the third body has been in contact. And, conversely, the glass or silk with which the third body has been in contact attracts or repels with less force than before. If a hand is drawn over the surface of an object after it has been charged with electricity, the electricity disappears. It has been conducted through the hand and the body to the earth. This phenomenon shows that the human body is a *conductor* of electricity. But most metals are much better conductors. Moist air and damp wood are rather poor conductors, while dry air, dry wood, porcelain, glass, hard rubber and sealing-wax are *non-conductors*, or *insulators*.

The term *dielectric* is used in preference to *insulation* when reference is made to the property of transmitting *induction*—a process quite distinct from ordinary transmission of an electric current. In *electrostatic induction*, a body electrostatically charged induces in a neighboring conductor a like charge in the parts farthest from the charged body, and an unlike charge in the nearer parts; the repelled like charge being removed by connecting any part of the

conductor momentarily with the earth, while the bound unlike charge spreads over the whole surface of the conductor and remains there even when the inducing body is moved away, or its charge neutralized, if the conductor is properly insulated.

Dielectric strength refers to the ability of an insulating material to resist rupture by high voltage, measured by the voltage necessary to effect a disruptive discharge through it. *Insulation resistance*, on the other hand, refers to the *ohmic* resistance *offer*ed by an insulating material to an impressed voltage, tending to induce a breakage of current through it. The term *dielectric* is used as a synonym for *insulator*, in the sense that a charge on one part of a non-conductor is not communicated to any other part. A charge given to a conductor spreads to all parts of the body. A dielectric possesses the property of transmitting electric force by *in*duction but not by *con*duction. A charge on one part of a non-conductor or dielectric is not communicated to any other part.

Jeans suggests that since the presence of magnetic energy is always associated with charges in motion, whereas electrostatic energy is present when all the charges are at rest relatively to each other, it may be proper to identify electrostatic energy with potential energy, and magnetic energy with kinetic energy[14]—i. e., energy due to motion of particles, rather than to energy of position, as of a coiled spring.

---

[14]Jeans, J. H., "Electricity and Magnetism," Page 483, 1911.

Statical energy is distinguished from "current electricity" by the fact that it accumulates on various bodies—is stored up—and as soon as proper connections are made, it discharges instantly. Statical electricity is used by physicians in electrical treatment of diseases and in X-ray work. Machines have been constructed that will produce very strong charges of statical electricity.

If a sufficiently large charge of electricity accumulates upon an insulated conductor in an electrical machine, it finally discharges itself, passing through the air to the nearest body. A flash of lightning is the result of an overcharge of statical electricity accumulated upon cloud particles, and may pass from cloud to cloud or descend to the earth.[15] Careful drivers of gasoline-tank wagons allow an iron or steel chain to drag on the roadway from a metallic connection, which conducts any surplus "static" to the ground. Failure to provide for such an emergency sometimes results in a terrific explosion with consequent loss of life.

About the beginning of the nineteenth century, the Italian scientist, Alessandro Volta (1745-1827),—and other physicists—discovered what has been called, after Volta, *voltaic electricity*, a current generated by chemical action between metals and different liquids as arranged in a voltaic battery. The term "volt"—the electromotive force which performs work at the rate of one joule per second (one watt)

---

[15]Benjamin Franklin was first to show (in a letter to Peter Collinson, written October 19, 1752) that lightning and electricity are one and the same thing. He was also inventor of the lightning-rod.

in producing a current of one ampere—was similarly derived.

It was learned that if two different metals, such as copper and zinc amalgam, are placed in a weak acid solution (such as one part H_2SO_4 to four parts H_2O), and connected by a wire fastened securely to the metals, a current of electricity (about two volts) will pass through the wire. Carbon (a non-metal) and a metal upon which the solution acts chemically may be used instead of two metals. There must be chemical action between the liquid and one metal, or there will be no current. Such a combination constitutes a *cell*, and two or more cells make a *battery*. The current starts with the zinc, is conducted by the solution to the copper, and thence by wire back to the zinc, completing a *circuit*. The zinc constitutes the negative pole (or electrode), the copper or carbon the positive pole (or electrode).

A cell frequently employed, where a weak (about 1.1 volts) but constant electromotive force ("E. M. F.") is required, is one devised by the English physicist, John D. Daniell (1790-1845). In this cell a copper sulphate solution containing a copper electrode is placed in contact (by means of a porous wall or partition—usually an unglazed porcelain cup) with a zinc sulphate solution containing a zinc electrode. The zinc electrode is negative to the copper. At each electrode there exists a potential difference between solution and electrode.[16] The

[16]"Potential" is analogous to level (or pressure) in hydrostatics or mechanics.

two electrodes being connected externally by a wire, a current of electricity will flow through the wire from the copper to the zinc, and zinc will dissolve at the anode (positive pole) and copper deposited on the cathode (negative pole). The current in this case, as in the preceding, is said to be produced by *voltaic action* and the cell is a primary battery. Voltaic action and *electrolysis*—the process of chemical decomposition (or dissociation of compounds or molecules)—by the action of an electric current produced externally (as by a dynamo) and forced through the cell, are essentially identical phenomena, and obey the same laws.[17]

The familiar *dry cell* contains no liquid which might be spilled, and is very useful for certain purposes, as in automobiles, and in operating door-bells. It is merely a voltaic cell whose chemical contents are made practically solid (or paste-like) by the use of some absorbent, as gelatine, sawdust, etc. In cells of the Leclanché type, a mixture of plaster of Paris, flour, and sal ammoniac takes the place of the solution which acts chemically upon one of the contained metals. When used up, a dry cell must be replaced by an entirely new cell. Two or more dry cells constitute a *dry battery*.

We have seen that there are two types of charged bodies, of which charged glass and charged silk are familiar examples. It was Dufay (1699-1739) who discovered that there

---

[17]For further explanation, see Shipley, Maynard, "The A. B. C. of the Electronic Theory of Matter," Little Blue Book Series, No. 603.

were two kinds of electricity, one of which he called *vitreous* (from glass) and the other *resinous* (from resin—amber). The terms "positive" and "negative" in relation to electricity were first applied by Benjamin Franklin, in 1756. To the electricity of the glass rod Franklin gave the name "positive" and to that of the sealing-wax (or hard rubber, amber, etc.) the name "negative." These names are now universally in use—though French physicists still speak of vitreous and resinous electricity.

I have spoken also of a positive pole (or electrode) and a negative pole (or electrode). The electrodes constituting the two poles of a current are also called the anode and the cathode, the former being the positive electrode and the latter the negative electrode.[18]

When it was learned that electrical charges could be distinguished by two opposing terms —positive and negative—it was natural to suppose that there were two distinct kinds of electricity, or "fluids." This was the view taken by the French chemist Dufay. But the German electrician Æpinus (1724-1802), in his great pioneer work, "*Tentamen Theoriae Electriciatis et Magnetismi*" (An Attempt at a Theory of Electricity and Magnetism—1759), considered the mathematical consequences of the hypothesis of a single fluid, attracting all matter but repelling itself. It soon became apparent, however, that he must assume either the existence of two electrical fluids or the

---

[18]See, in this connection, Shipley, *Op. cit.*

mutual repulsion of material particles. He chose the latter theory. He explained the phenomena of the opposite poles as results of the excess and deficiency of a "magnetic fluid," which was dislodged and accumulated in the ends of the body, by the repulsion of its own particles, and by the attraction of iron and steel, as in the case of induced electricity.[19]

Æpinus, who was unquestionably one of the greatest physicists of the eighteenth century, devised a method of examining the nature of the electricity at any part of the surface of a body, by which means he was enabled to ascertain its distribution. He found that the distribution was in agreement with the attractions and repulsions which objects exert when they are in the neighborhood—"electrical atmosphere"—of electrified bodies. Today we say that such bodies are electrified by induction.

The Æpinian theory of electricity and of magnetism was modified and presented in a new form (in 1788) by Coulomb, with two fluids instead of one. His first task, before reducing the theory to calculation, was to determine the law of the forces involved—not being satisfied, for example, with Newton's assumption that the attractive force of magnetism is inversely to the *cube* of the distance. Mayer in 1760, and Lambert a few years later, had found the law to be that of the inverse square. Coulomb desired experimental confirmation of this law before accepting it as established.

---

[19] A very similar hypothesis was read before the Royal Society by Henry Cavendish, in 1771, the work of Æpinus being unknown to him at the time.

This he secured by means of his torsion-balance (about 1784).[20]

It was in pursuance of this investigation that Coulomb brought to light for the first time the fact that the directive magnetic forces which the earth exerts upon a needle is a constant quantity, parallel to the magnetic meridian, and passing through the same point of the needle whatever be its position.

Barlow, who had adopted the two-fluid hypothesis, showed that the magnetic "fluids" were collected at the surface of spheres (of iron), the surface being the only part in which there could be detected any magnetism. He demonstrated that a shell of iron produces the same effect as a solid ball of the same diameter. Poisson's later analysis (1824) showed that this was a consequent to be expected. Merz has well said that what Laplace did for Newton was done by Poisson (1781-1840) "for Coulomb's elementary law of electric and magnetic action, and on a still larger scale by Gauss, who worked out the mathematical theory and applied it to the case of the magnetic distribution on the earth's surface. In England, already before Coulomb's researches were published, Cavendish had, likewise by a combination of experiment and calculation, es-

---

[20]By means of this instrument very minute forces can be accurately measured, such as electrostatic or magnetic attraction and repulsion, by the torsion (turning or twisting) of a wire or filament, the angle of torsion being proportional to the amount of force exerted.

tablished the elementary formulae and properties of electrical phenomena."[21]

Benjamin Franklin, the first American to gain international renown as a scientist, adopted and developed a "one fluid theory of electricity." On this supposition the parts of the fluid repel each other, and the excess in one surface of the glass—for example—repels the fluid from the other surface. The fluid itself was regarded by Franklin as positive, the part of the other (negative electricity) being taken by ordinary matter, the particles of which were supposed to repel each other and attract the positive fluid, just as the particles of the negative fluid did on the two-fluid theory.

On both the two-fluid and the one-fluid theories, as we have seen, the particles of the positive fluid repelled each other by forces varying inversely as the square of the distance between them—as shown by both Æpinus and Coulomb. This is true also of the particles of the negative fluid. The particles of the positive fluid attracted those of the negative fluid. In Franklin's one-fluid theory it was the ordinary particles of matter which attracted the positive fluid and repelled one another. Both theories from their very nature imply, as Sir J. J. Thomson long ago (1906) pointed out, the idea of action at a distance.

In his very interesting book, "Matter and Energy" (1912), Professor Soddy says: "All electrical phenomena can be explained as well on the one-fluid as on the two-fluid idea, but

[21]Merz, Henry, "History of European Thought in the Nineteenth Century," Vol. I, Page 362.

our ignorance at the present time as to whether there are two kinds of electricity or one is fundamental. Until the question is settled, the hopes that have been entertained that, through the study of electricity, we shall be able to arrive at a philosophical explanation of matter, are likely to prove unfounded."

Our modern view of electrification bears a close resemblance to the one-fluid theory of Franklin, whether we suppose there is one kind of electricity, or two kinds. At all events, if there be such a separate force, or such units of energy, as "positive" electricity, it has never been isolated, as have been the negative atoms or electrons. Negative electrification is but a collection of these negative corpuscles or unit charges. The particles of the "electric fluid" of Franklin correspond to these electrons.

"Instead of taking, as Franklin did, the electric fluid to be positive electricity, we take it to be negative," says J. J. Thomson, in his "Corpuscular Theory of Matter" (1906). And "the transference of electrification from one place to another is effected by this motion of corpuscles from the place where there is a gain of positive electrification to the place where there is a gain of negative. A positively electrified body is one that has lost some of its corpuscles."[22]

---

[22]For a recent work on modern electrical theory, see Starling, Sydney G., (head of the department of physics in the West Ham Municipal College, London), "Electricity," London, 1922. For the pioneer work of Ampère, see his *"Theorie des Phenomenes Electrodynamiques,"* 1826.

CHAPTER 5

MODERN MAGNETIC THEORY

We have already shown how the magnetism of a magnet is converted into electricity, by means of rotating coils cutting the lines of magnetic force in the "field." The energy used to drive the machinery may, of course, be derived either from water-power or by steam. Gravity gives energy to falling water; chemical energy produced by the oxidation of coal becomes heat energy, which in turn causes the expansion of steam, which produces energy of motion in a piston; and this motion, transmitted to the parts of an engine to a dynamo, produces electrical energy. When the electric current from the dynamo has been conducted to any desired point by cables, another motor, acting in the opposite sense, causes the electricity to change back again into the original mechanical energy, less the loss due to imperfections in the operation. Here we have, then a clear picture of what is meant by the phrase, *transformation of energy.*

But another question naturally arises at this point. We know that with a finite quantity of magnetism we can produce an unlimited quantity of electricity. Yet we add no new material, no source of supply, to the dynamo. Let the rotating coils continue to cut the lines of magnetic force in the magnetic field, and the magnetism of the magnet will be transformed into current electricity—furnishing a literally exhaustless supply from the great storehouse of nature. For us the energy of the

universe is infinite in quantity. The reservoir of energy is exhaustless, and the dynamo is man's open sesame.

But just here the very interesting question arises: Is the inexhaustible supply of electric current with the expenditure of a limited quantity of magnetism fully explained by saying that it is due to the rotational movement of the coil? Can the mere rotation of a metal in a magnetic field actually *create* an endless supply of available energy? Not likely! As Dr. Gustave Le Bon well says: "Such a metamorphosis would be as marvelous as transformation of lead into gold by simply shaking it in a bottle. Another interpretation must be sought for the phenomenon."

Now, a current of electricity is known to be a stream of electrons (negative charges) flowing along or in a conductor; and an electron is an atom of—*energy*. But where was this energy stored? "In the all-pervasive ether," say many physicists. "There is no ether," say others. The electromagnetic field represents energy storage *in space*—not in a universal, incomprehensible, paradoxical something called "ether."

A field of *energy* is intelligible. It takes the place of the conception of action at a distance and of the ether. No "ether" need be postulated as the carrier of the field energy in space. It is its own carrier. "Energy is the only real existing entity, the primary conception, which exists for us because our senses respond to it" (Steinmetz).

"Lines of force," says Dr. N. R. Campbell,

the famous English physicist, "are just lines of force, independent for their existence of all surrounding bodies, and there is no more to be said about them. . . . Our Electrical theory, so far from providing additional support for the conception of the ether filling all space, does not require such a conception at all."

Dr. Le Bon finds the exhaustless source of electricity in the interior of atoms. The atoms in one pound of earth contain enough energy to run all the factories, mills, railroads, etc., and light all the cities and villages of the United States, for a month, Steinmetz tells us. "It would," he states further ("Relativity and Space," Page 45), "supply the fuel for the biggest transatlantic liner for 300 trips from America to Europe and back. And if this energy of one pound of dirt could be let loose instantaneously, it would be equal in destructive powers to over a million tons of dynamite."

From the above statement, we may well understand Dr. Le Bon's interpretation of the work of a dynamo: "Matter being easily dissociated and constituting an immense reservoir of intra-atomic energy, it is enough to admit that the lines of force seized upon by the conducting body (the coils), which cuts them and causes them to flow in the form of an electric current, are constantly replaced at the expense of the intra-atomic energy. This latter being relatively almost inexhaustible, a single magnet can furnish an almost infinite number of lines of force."

It can be shown that the kinetic energy of

one kilogram (2.2 pounds) weight of matter is about 9000 millions of millions of kilogram-meters, or 25 thousand million kilowatt-hours (a kilowatt-hour=1000 watt hours). This means, in other words, that the quantity of energy in the atoms of 2.2 pounds of ordinary matter is thousands of million times greater than the energy of an equal quantity of coal, *released by chemical combustion.*

Estimating the total energy consumed during the year on earth for heat, light, power, etc., as about 15 millions of millions (=15,000,000,-000,000) of kilowatt-hours, Steinmetz tells us that 600 kilograms, or less than two-thirds of a ton, of "dirt," if it could be disintegrated into energy, would supply all the heat, light and energy demand of the whole earth for a year.

Several eminent physicists are now specializing on the problem of how to liberate and control intra-atomic energy for man's uses—or abuses. Bearing in mind the present intellectual, moral and economic status of our "leaders of thought" and their followers, and remembering that one pound of common soil contains intra-atomic energy equal in destructive power to more than a million tons of dynamite, let us hope that the secret of releasing and "controlling" intra-atomic energy will not be discovered in our day and age.

CHAPTER 6

PROOF THAT ELECTRONS ARE ATOMS OF ELECTRICITY

THE ZEEMAN EFFECT

Heinrich Hertz demonstrated in 1887 that he could produce in the "ether"—or at least in

space—what are now known as "wireless waves," by allowing a charge of electricity to oscillate to and fro. Larmor and Lorentz were, at the same time, endeavoring to formulate a theory which would account for the production of the far shorter light-waves.

Lorentz supposed that each atom contained one or more infinitesimal particles, or electric charges (electrons), whose excessively rapid vibrations caused the emission of light-rays. Maxwell showed that there must be a close connection between light and electricity, a theory converted into demonstrable fact by the work of Hertz.

That there is a similar relation between light and magnetism was the firm conviction of Faraday. In 1845, he placed a block of very dense glass between the poles of the most powerful electromagnet produceable at the time. Before turning on the switch, he allowed a beam of light to pass through the glass, producing "polarization"—a modification of light-rays resulting from their reflection (in this case from a crystalline substance), imparting to the beam a definite direction—the plane of vibration or plane of polarization. When the switch was closed, permitting the flow of the electric current, which produced the magnetic field, the beam of light was "rotated." That is, the beam of light was "plane-polarized" by the crystal, and "rotated" by the magnetic field; i. e., now changed into two "circularly polarized" rays, one a left-handed motion and the other a right-handed motion (in the direction of the hands of a watch).

This could be accounted for only on the

theory that light is affected by magnetism, since the beam was not rotated by the glass alone—in itself a very important discovery. But the experiment did not yield Faraday an answer to the question uppermost in his mind: namely, can a magnetic field change the rate of vibration of a light-emitting particle? That is to say, in effect, can a magnetic field cause a ray of light to shift its normal place in the spectrum?

It was not until 1862, seventeen years after the experiment just described, that Faraday attempted to solve this important theoretical problem. He now placed a sodium flame in front of the slit of the spectroscope, which normally yields two characteristic yellow lines (the D lines of the spectrum), and observed them with the best spectroscope at his command, under the most powerful electromagnetic field which he could produce. No change from the normal could be detected. Other observers tried the same experiment, but with negative results. We know that his theory was well founded, and that only the lack of a better spectroscope and a more powerful magnet prevented his discovery of what is now known as the Zeeman effect—a discovery which has already thrown a flood of light on a number of difficult physical problems.[23]

---

[23]For a good summary of the main results concerning the Zeeman effect, see von Auerbach, Felix, "*Moderne Magnetik*," Leipsic, 1921. An excellent account of the quantum treatment of the Zeeman effect may be found in Chapter XV (Series Spectra) of Dr. N. R. Campbell's "Modern Electrical Theory, Supplementary Chapters," Cambridge University Press, 1921.

Working with much more powerful apparatus, but following the same method of procedure employed by the immortal Faraday, Dr. Pieter Zeeman, of Leyden, succeeded, in 1896, in experimentally demonstrating the close relationship between light and magnetism. Dr. H. A. Lorentz, then Professor of Physics in the University of Leyden, now mathematical physicist at the Norman Bridge Laboratory of Physics, Pasadena, California, had predicted the nature of the change in the spectral lines to be expected, and this knowledge was used by Dr. Zeeman as a check on his results.

Using a Rowland grating, instead of a less efficient prism spectroscope, Dr. Zeeman found that when a relatively weak electric current was applied, the two sodium lines were merely widened. In a still more powerful magnetic field, each of the lines was decomposed into two or three components, when the lines of force were parallel to the line of sight.[24] Moreover, the rays of the components of each line "were not those of natural light," but were "polarized in a characteristic way," i. e., were

[24]It seems that this phenomenon had previously been observed by M. Fievez. (Cf. Michelson, Dr. Albert A., "Light Waves and Their Uses," Page 107.) "He thought that each separate line was doubled or quadrupled." Lockyer, in 1866, observed that some of the lines in a sun spot spectrum were widened. Prof. Charles Young and W. M. Mitchell observed that some of the lines were even double, but it was not suspected that these phenomena were caused by a strong magnetic field in sun-spots, brought about by free electrons being driven around in a vortex movement. In fact, Mitchell referred to the doublets as "reversals."

circularly polarized in opposite directions—"the direction of the vibration depending in a simple manner on the direction of the magnetic lines of force."[25]

The same effect has more recently been produced in the case of the spectral rays of nearly —if not quite—all the other elements. The process, as described by Dr. George Ellery Hale, is very simple: "We place our iron ore or spark between the poles of a powerful magnet, and photograph its spectrum. The lines behave in the most diverse way, some splitting into triplets, others into quadruplets, quintuplets, sextuplets, etc. One chromium line is resolved by the magnet into twenty-one components. . . . The distance between the components of a line is directly proportional to the strength of the magnetic field.[26]

The meaning of this splitting and polarization of light-rays in the magnetic field is that, as Lorentz had predicted, there are present in the luminous vapor vibrating particles nega-

---

[25]Zeeman, *"Les Lignes Spectrales et les Theories Modernes." Scientia,* January 1, 1921, Page 18 (Vol. XIX, No. CV—I).

[26]Hale, "Ten Years Work of a Mountain Observatory," Pages 29-30, Washington, D. C. (Carnegie Institution of Washington), 1915. See also, Babcock, Harold D., "The Zeeman Effect for Chromium," *Contributions from Mount Wilson Observatory,* Vol. II, Paper No. 52; also "The Correspondence between Zeeman Effect and Pressure Displacement for the Spectra of Iron, Chromium and Titanium," Arthur S. King, Loc. *cit.,* Paper No. 46; and "The Zeeman Effect on the Sun," Adriaan van Maanen, *Publications of the Astronomical society of the Pacific,* Page 24, Vol. XXXIV, No. 197 (February, 1922).

tively charged, or "electrons." Measurement of the distances apart of the components of the triple line reveals the relation between the charge and the mass of the particles.[27]

It is interesting to add that the disturbances in the magnetic field, as observed by Zeeman, were precisely of the amount calculated by Lorentz purely on theoretical grounds, and the mass of the electron was found by this method to be 1/1840 that of the hydrogen atom. By a different method, Sir J. J. Thomson obtained a value of 1/1800 the mass of the hydrogen atom; while Dr. Robert A. Millikan, by means of his famous "electrical balance," derived a value of 1/1845 that of the hydrogen atom.[28]

In his monograph of 1913, Zeeman remarked that in discoveries of optics "we may always cherish the hope that they will lead ultimately to applications to astronomy." So far as study of solar phenomena and the Zeeman effect are concerned, this hope has been fully realized, and attempts are being made to extend the applications of this method of investigation to other stellar bodies. Of the general value of Zeeman's discovery, Dr. Hale writes: "The complex phenomena of the Zeeman effect (as revealed in a comparative study, with powerful spectrographs, and an intense magnetic field, of the lines of a long list of elements) furnish ma-

---

[27]Zeeman, *Loc. cit.*, Page 18. See also the classical monograph by the same author, "Researches in Magneto-Optics," London, 1913.

[28]Millikan, *Physical Review*, 2, 143 (1913); "The Electron," 1917 (revised edition, 1924). See also, *Proceedings of the National Academy of Sciences*, 3, 314 (1917).

terial available for wide generalization, important in their bearing on theories of radiation and atomic structure" (*Op. cit.*, Page 36).

Discovery by Hale and his co-workers at Mount Wilson of the Zeeman effect in sun-spots led to the very important conclusion that these disturbances represent whirling vortices of electrons, producing a magnetic field. "The strength of the magnetic field produced, which is measured by the degree of separation of the triple lines, increases with the diameter of the spot. . . . It has long been known that sun-spots usually occur in pairs, and our study of the Zeeman effect indicates that the two principal spots in such a group are almost invariably of opposite polarity" (Hale, Op. cit., Pages 28-31).

The sun, like the earth is now known to be a magnet, whose general magnetic field is about 80 times as intense as that of the earth. At the distance of the earth the solar magnetic field is not appreciable, "since the effect of one pole counteracts the equal and opposite effect of the other pole."

Were it not for our knowledge concerning the Zeeman effect, it would not yet be known for a certainty that the sun is a vast magnetic globe, since this fact could not be assumed to be a source of the sun's gravitational power. "Indeed," says Dr. Hale,[29] "its attraction cannot be felt by the most delicate instruments at the distance of the earth, and would still be unknown were it not for the influence of magnetism on light. Auroras, magnetic storms,

---

[29] "The New Heavens," Page 70. New York, 1922.

and such electric currents as those that recently deranged several Atlantic cables are due, not to the magnetism of the sun or its spots, but probably to streams of electrons, shot out from highly disturbed areas of the solar surface surrounding great sun-spots, traversing 93 million miles of the ether of space, and penetrating deep into the earth's atmosphere."

By means of the famous 150-foot tower telescope at Mount Wilson, which produces at a fixed point in a laboratory an image of the sun about sixteen inches in diameter, the magnetic phenomena of sun-spots are being studied to great advantage, the enlarged sun-spots making possible separate observation of their various parts. "This analysis is accomplished with a spectroscope 80 feet in length, mounted in a subterranean chamber beneath the tower." By this means the very important discovery was made by Director Hale that the entire sun, rotating on its axis, is a great magnet. "Hence," says Dr. Hale, "we may reasonably infer that every star, and probably every planet, is also a magnet, as the earth has been known to be since the days of Gilbert's '*De Magnete*.' Barnett has succeeded in producing magnetism by rapidly whirling masses of metal in the laboratory" (Hale, "The New Heavens," Pages 69-70).

More recently (October, 1922), Hale, Ellerman and Nicholson, all of the Mount Wilson Observatory, have detected *invisible* sun-spots by searching for evidences of the Zeeman effect in promising regions, such as areas of flocculi following a large spot. "A special

polarizing apparatus permits very small magnetic fields to be found by the alternate widening to red and violet of the iron triplet Lambda 6173," say Hale and Adams ("Summary of the Year's Work at Mount Wilson," Publications of the Astronomical Society of the Pacific, October, 1922, Pages 269-70 [Vol. XXXIV, No. 201]). "The results confirm the view that a spot represents a vortex, which becomes visible only when the cooling due to the expansion (of gases) is sufficiently great to produce a perceptible decrease in the brightness of the photosphere."

From what has been said, it is evident that Dr. Zeeman's desire to see the results of his discovery applied to the study of astronomical problems has been fully realized.

THE STARK EFFECT

Lorentz's prediction regarding the effect of a strong magnetic field on spectral rays, and the movements of electrons in the field having been confirmed so brilliantly by Zeeman, it remained to ascertain what effect, if any, would be exerted by electrical force on light-rays.

The answer to this problem was given by Prof. Johannes Stark, at Aix-la-Chapelle, in 1913, by his skillful demonstration of the electrical decomposition of the spectral rays of hydrogen, helium and lithium..[30]

Stark's task was a more difficult one than Zeeman's, owing to the fact that he had to deal

---

[30]Cf. Stark, *"Die Atomionen chemischere Elemente und ihre Kanastrahlenspektra,"* Berlin, 1913. See also, *"Elektrische Spektralanalyse chemischen Atome,"* Leipsic, 1914.

with luminescent gases, which, being conductors, exhaust the electrical field almost before any observations can be made, even hurriedly. This condition gives rise to difficulties in connection with the application of the electric field. But these were very ingeniously met by employment of highly evacuated tubes and the light emitted by the "canal rays"—positively charged particles similar to the alpha rays.[31] Where the rays issue from the perforated electrode (or "canal"), the conduction of electricity is weak, and Stark was able to apply intense electric fields in a small space. It was then found that the diffuse rays of the spectrum produced were strongly influenced, while the "sharp" rays were less so.

The attentive reader will note that this result was in marked contrast with the *magnetic* decomposition produced in the Zeeman experiment, in which tne rays did not differ one from another in respect to the degree of their decomposition. In all the details there is a difference between the electric and magnetic decompositions, and analogy existing only in this, namely, that in both cases polarized rays were obtained. In both cases the results produced were due to disturbance of the *motions of electrons*, giving rise to broadening, displacement or other modifications of spectral laws. Both "effects" confirm the theoretical view of Max-

[31]Called "canal rays" by the German physicist, Eugen Goldstein, who, in 1886, first obtained them by the use of a perforated cathode; that is, he used a metallic tube for a cathode, through which tube, called by Goldstein a "canal," the rays issued.

well, namely, that light is an electro-magnetic phenomenon.

Faraday's famous question is thus more than answered in the affirmative: not only is the rate of vibration of "atoms" (electrons) changed by a magnetic field, but also under the action of an electrostatic field, producing *decomposition* of certain spectral lines, which are usually *polarized*, as in the Zeeman effect.

As a result of his intensive investigations of the Zeeman effect, Dr. Henri A. Deslandres, Director of the Astrophysical Observatory at Meudon (a southern suburb of Paris), proposed a new general formula which represents the series relationship of the component lines and heads of bands both for emission and absorption spectra. According to his experimentally-derived law, "the origin of these radiations may be found in the transverse and longitudinal vibrations of the atoms."

The lamented Dr. P. S. Epstein, a gifted pupil of Sommerfeld, who—like Mosely—fell a martyr to the World War, succeeded in applying the quantum dynamics to the Stark effect, whereby the motions of the electron in producing the H-beta (in the blue-green) and H-gamma (in the violet) lines observed, "are accounted for with great accuracy" (Loring, "Atomic Theories," Page 67).

It may be said in conclusion, that the most promising attempts fully to explain the phenomena of the Zeeman and Stark effects seem to be made from the point of view of Planck's Quantum Theory of Light. On the other hand,

it must be admitted that there has not been, so far as I can ascertain, any theory proposed which explains *all* of the phenomena involved.

CHAPTER 7

THE DISCOVERY OF WIRELESS TELEGRAPHY

The experimental foundation for the discovery of wireless telegraphy was laid by the researches of Faraday.[32]

Accepting Faraday's physical views as a point of departure, James Clerk Maxwell (1831-1879), Professor of Experimental Physics in the University of Cambridge, began (about 1860) the development of his constructive speculations in electrical theory which culminated in the now universally accepted electromagnetic theory of light.[33]

Fourteen years after the publication of Maxwell's classic treatise, Heinrich Hertz (1859-1894)—a brilliant pupil of Helmholtz (1821-1894)—succeeded in producing electrical discharges from a Leyden jar, which oscillations in turn gave rise to electro-magnetic waves of far greater length than any previously known.[34]

Hertz demonstrated also that the velocity of propagation of these waves was the same as that of light-waves—approximately 186,000

---

[32]See his "Experimental Researches in Electricity," *Everyman's Library Series.*

[33]Maxwell, James Clark, "Treatise on Electricity and Magnetism," 1873.

[34]The theoretical investigation of the mode of discharge of a condenser had been given by Sir William Thomson (later Lord Kelvin) in 1853, in the *Philosophical Magazine* for June of that year.

miles a second, equivalent to about seven times the circumference of the earth in one second. It was shown that the only difference between the Hertzian ("wireless") waves, for example, and the light-waves, is in their respective length, or, reciprocally, their rates of vibration per second. Hertz later demonstrated that these invisible waves produced by a Leyden jar could be reflected, refracted, and polarized, as in the case with the far shorter light-waves or rays.[35] These results had been predicted by Maxwell.

In this great discovery the foundation for wireless telegraphy and wireless telephony was laid—for Hertz had found what are now known as "wireless" or radio waves—destined, perhaps, to revolutionize our methods of obtaining power for machinery, and for transportation, as they have already revolutionized our methods of communication. Hertz had done more than this: for his investigations made possible a far more satisfactory research into the structure of atoms.

"If we were asked to pick out one date that

---

[35]When all the atoms and molecules of a substance vibrate in one plane, e. g., as the plane of a train of waves would be if drawn on this page, the wave is said to be *polarized*. Ordinarily, light-rays are sent out from particles vibrating in different planes; they may be vertical or horizontal, or diagonal, or they may move in a curved path—circles or ellipses. Ordinary light-vibrations are mixed up together, vibrating in all planes, and special devices—"polarizers"—are required in order to separate any one particular vibration from the rest.

stands out more prominently than others in our acquisition of knowledge bearing upon the structure of matter," says Dr. Albert C. Crehore, "it might be this epoch-making work of Hertz."[36]

While it is true that the waves that Hertz discovered and measured "differ from light-waves merely in wave-length or period of vibration and quality," on the other hand the difference in wave-length is so great that no instrument had as yet been devised to measure or detect waves that were meters long, as compared with light-waves but a minute fraction of a centimeter in length.

It was Hertz's task—following up Maxwell's prediction—to devise an instrument which would detect waves not cognizable by our senses alone. For this purpose he used a simple loop of wire with the ends brought near together, each terminating in a metal ball. When these balls were brought almost into contact, a small electrical spark was seen to pass between the balls when the "oscillator"—the apparatus used to generate the oscillating currents, or electric waves, of high frequency—was set in operation.[37]

Hertz not only proved that the speed of electric waves is the same as that of light, and that they are subject, under certain con-

---

[36]Crehore, Dr. Albert C., "The Mystery of Matter and Energy," Page 28, New York, 1917.

[37]By means of an induction coil coupled to a circuit containing capacity terminals, thus forming an "oscillatory circuit."

ditions, to "interference" as are light-waves, but he also succeeded in actually measuring the length of the waves produced by his crude apparatus. This was accomplished by producing what are known as "standing waves," analogous to the sound-waves produced by an organ-pipe. Moving his detector slowly along the wire, Hertz observed that the spark would appear when a certain interval of space was reached, and as he continued to move the detector the sparks would disappear and reappear at regular distances. He rightly concluded that these points of disappearance and reappearance of the spark corresponded to the nodes and loops of the "standing waves," representing the wave-length of the electrical undulations.

It has since been established that the difference in wave-length between the electric undulations produced by Hertz and those of light-waves may be enormous or quite moderate. Professor Michelson tells us that "a telegraphic wave, which is practically an electromagnetic disturbance, may be as long as 1000 miles. The waves produced by the oscillations of a condenser, like a Lyden jar, may be as short as 100 feet; the waves produced by a Hertz oscillator may be as short as one-tenth of an inch. Between this and the longest light-wave there is not an enormous gap, for the latter has a length of about 1/1000 inch. Thus the difference between the Hertz vibrations and the longest light-wave is less than the difference between the longest and shortest light-waves, for some of the shortest oscillations are

only a few millionths of an inch long. Doubtless even this gap will soon be bridged over.[38]

The Hertz apparatus was greatly improved by Auguste Righi, in the University of Bologna. In the same class in physics was Marconi, who began his fruitful experiments in 1895, one year after Sir Oliver Lodge had perfected the coherer. Lodge's coherer, used by Marconi in his early work, consisted of a glass tube containing a pinch of nickel and silver filings in equal parts. Crude as this detector was, judged by present-day standards, it materially improved the conductivity of contact metals in the case of Hertzian waves.

In 1899 wireless communication was established across the English Channel, and in 1902 Marconi sent the first wireless message from England to America. Today, wireless waves measuring miles from crest to crest are being employed in the transmission of messages from points separated by thousands of miles, and the human voice has already been carried across the Atlantic by radiophone, but only in one direction.

The wireless sending and receiving station of the Dutch government, at Kootmyck, in the Province of Gelderland, is equipped to employ a 12,000-meter wave-length in sending and receiving simultaneously messages between Holland and Java, 7,500 miles distant. It has the

---

[38]Michelson, Dr. A. A., "Light Waves and Their Uses," Pages 160-61. The gap was closed during the year 1924, heat-waves being measured which were of such great length as to merge into the shortest Hertzian or "wireless" waves.

same capacity as our Long Island (Rocky Point) station, and is therefore one of the biggest in the world.

On December 19, 1922, a long distance phonograph which records sounds made hundreds of miles away was demonstrated to the Society of Western Engineers, by E. H. Colpitts, of the Western Electric Company. The transmission of electric power by radio is as yet but a dream; but it is a dream which may come true within the next five years.[39]

Signals are now being received from stations situated at distances as great as 12,000 miles, made possible, it is believed by the existence of an electrical conducting layer—electrified dust expelled by the sun—some 150 miles in depth, the bending of the radio-waves around the earth being caused by diffraction. Some unknown factor is operating to give the signals a strength millions of times greater than can be accounted for at present by any plausible theory, according to Prof. J. A. Fleming (Fifth Henry Truman Wood Lecture before the Royal Society of Arts, London, 1922).

It is not reasonable to assume that no other electromagnetic waves remain to be discovered. We may yet hear "the roar of the sun-spots," though Edison's experiments along this line were unsuccessful. What, indeed, were the mysterious "signals" occasionally reported as having been received at Marconi wireless stations—registered, it was reported in the press,

---

39See an interesting article on this question in *Science and Invention*, December, 1922, Page 744 (Vol. X, Whole No. 116).

"only when a minimum of sixty-five-mile wave-lengths had been established," but waves issuing from the mighty sun, 93,000,000 miles distant? However, Marconi tells us that one of the "signals" comes as three short raps—"S" in the Morse code. He believes that these "signals" may have been sent out from Mars or Venus. Similar mysterious "signals" were reported by wireless stations in different parts of the world during the apposition of Mars in August, 1924.

"Outside of the radio-waves that are floating about there may be hundreds of others which we have not as yet been able to register. . . . There may be many other waves coming to us from the sun, of which we have no knowledge today. . . . The human ear cannot hear below eight vibrations per second and not higher than about 30,000 vibrations per second. Certain animals can hear below and above that scale. By means of our vacuum tubes certain researches indicate that a tremendous amount of noise goes on below the eight vibrations per second, and still more noise above the 30,000 vibrations. Entirely new worlds lie in these two directions, of which nothing is known today. The vacuum tube is likely to solve these mysteries and take us into the uncharted worlds, far into the unknown, within the next few years."[40]

In March, 1922, the late Dr. Charles P. Steinmetz said that he considered well founded the supposition that performances of low-power

[40]Gernback, H., Editorial in *Science and Invention,* December, 1922.

radio sending apparatus in transmitting messages to surprising distances gave an indication that the radiations peculiar to wireless transmission pass with equal ease through the earth or through the "ether."

Such radiations would be in accordance with accepted electrical laws, as the ground, to which both the sending antennae and the receiving set are connected, would act as a return circuit for the current. Similarly, water might serve as a medium for radio conversations between ships, or between ships and the land.

Moreover, it was announced during the same month that wireless telephony had been revolutionized by the successful performances of the duplex transmitters which the General Electric Company had just completed. Conversations were held between New York and passengers aboard the steamer "America," which, at the time, was at a distance of 360 miles from shore.

The three-electrode audion or vacuum tube was perfected in 1912, making radio-telephony possible. In 1921, Reginald A. Heising, a young physicist working for a degree of Master of Science at the University of Wisconsin, conceived the brilliant idea of putting into the vacuum tube the amount of energy produced by the voice, and then getting it out many times amplified in the form of high-frequency power in the antenna. This problem he soon solved, so far as the principle of the modulation system was concerned, and in 1922 the

practical problem was worked out and the method all but perfected.

All these great utilitarian advances have been made possible by the researches of men interested in the advancement of knowledge for its own sake. As has been pointed out recently by Dr. Hale ("The New Heavens," Pages 87-88), "Faraday, studying the laws of electricity, discovered the principles which rendered the dynamo possible. Maxwell, Henry and Hertz, equally unconcerned with material advantage, made wireless telegraphy possible. . . . Wireless telephony and transcontinental telephony without wires were both rendered possible by studies of the nature of the electric discharge in vacuum tubes."

In an interview in December, 1922, Dr. Nikola Tesla gave it as his opinion, based upon experiments already carried out in his own laboratory in New York City, that power flashed through space by radio will soon be employed in all the world's activities.

"Besides bridging enormous distances in flight and wireless conversation," he said, "modern science will span the earth with power flashed through the air by radio. Airplanes and ships and trains will carry no fuel, but will run by transmitted energy. With wireless power no one—explorers, travelers, campers—need be cut off from civilization and its comforts.

"Not only that, but we shall see at great distances by aid of wireless energy. And seeing our neighbors across the oceans will make for a united social and political world."